Interim Design Report

Micromouse X Subsystem

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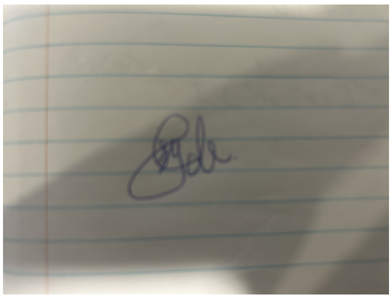

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Chapter 1

Introduction

1.1 Problem Description

A maze is 'a network of paths and hedges designed as a puzzle through which one has to find a way'.A micro-mouse is a small autonomous robot that is designed to solve an unknown maze and therefore find the center in the quickest time possible.The micro-mouse has a number of subsystems that have different functionalities.The micromouse needs a core which is the motherboard and processor board which will store and process the necessary information as the micromouse navigates through the maze.The subsystem that is designed for this particular project is a sensing subsystem. The sensing subsystem purpose is to be the eyes of the micro-mouse as it navigates through the maze.This means that the sensing subsystem will be used to detect whether a particular obstacle is in the path of micro-mouse and thus notify itself that it can not turn nor continue it that direction.

1.2 Scope and Limitations

The scope of the project is to design the sensing subsystem. The sensing subsystem should be able to detect objects in the far left of the robot, right in-front and far right of the robot. This information regarding detection should be sent to the STM32L476 which lies in the processor board. The processor board will be responsible in showing the output to users. As all subsystems and designs are finalised, they will be connected to the motherboard. Albeit there are still limitations of the designing of the sensing subsystem. The design has a limited pcb board size and size. This is to ensure that the board is not large enough for the overall micro-mouse and won't have a large impact on the movement of the micro-mouse.The components used,during the designing of the subsystem, must be readily available and in stock, as the PCBs will be ordered from JLCPCB. Components that are out of stock cannot be used for the design. The budget of the entire project will be a limitation to the designing of the subsystem.

1.3 GitHub Link

https://github.com/Sipho-Junior/EEE3088F-MicroMouse

Chapter 2

Requirements Analysis

2.1 Requirements

Requirements can be defined as a specific criteria, capabilities, conditions, or qualities that a product, system, or service must have in order to meet the needs or expectations of the stakeholders.Requirements serve as the foundation for the design, development, and verification of a product or system.The requirements for a micro-mouse sensing module are described in Table 2.1.

Table 2.1: User and functional requirements of the sensor subsystem.

Requirement ID	Description
RID1	Detect obstacles - The micro-mouse must be able to detect the wall at 3 different locations : 1) Far right of the robot. 2) Directly in-front of the robot. 3) Far left of the robot
RID2	Power efficiency - The sensing subsystem must have switching means that will save power.
RID3	Size and Fit - The sensing subsystem must fit within the pins provided on the motherboard which are 2x14. The overall size and shape of the PCB should be optimized to minimize the distance from the center of rotation.
RID4	Budget Constraint - The sensing subsystem must be designed within the budget constraints of R360.
RID5	Integrate with processor - The sensing subsystem must interface with the provided processor board which has 2x14 pin headers. It must provide the input to the processor board that contains 3 LED's.
RID6	Power On - Must operate on the voltage given by the power subsystem.
RID7	Calibration - Calibrate the sensor in a specific environment thus it will decrease the effects of ambient light.

2.2 Specifications

Specifications provide a more technical definition of how the requirements will be reached. They describe the specific design parameters and operational characteristics that the final solution must contain for the particular design.The specifications, refined from the requirements in Table 2.1, for the micro-mouse sensor module are described in Table 2.2.

Table 2.2: Specifications of the sensing subsystem derived from the requirements in Table 2.1.

Specification ID	Description
SID1	Power: The sensor subsystem must operate on a power supply of 3.3V.
SID2	Utilization of pins from the processor board, which are connected to the micro-controller, PA3, PA4, PA5, PA6 etc. for analog sensor inputs.
SID3	Power consumption: The maximum current draw for the sensing subsystem should be no more than 400mA.The sensor subsytem should have switching means when not in operation.
SID4	Reliability: The sensing subsystem should have a detection range of at least 200mm.
SID5	Size: The PCB should be designed to minimize the distance from the center of rotation on the motherboard and must fit in the pins being provided.The PCB should be less than 70mm x 35mm in size.
SID6	Code: A code must be written that will send sensor output information to the micro-controller.

2.3 Testing Procedures

A summary of the testing procedures detailed in Acceptance Testing table is given in Table 2.3.

Test ID	Description
AT00	Using the multimeter to test for continuity across the components.Measuring the overall size of the board and checking if pin headers are placed correctly.
AT01	Using the supply voltage to power on the IR LED. This test will tell one if the supply voltage is sufficient enough to power the IR LEDs in the circuit and therefore enabling the IR LED to emit light.
AT02	Infrared light cannot be seen with the naked eye. Testing whether the IR LED emits infrared light when connected to the power supply. This test will confirm if the LED is a normal LED that emits visible light or an LED that emits infrared light.
AT03	This test needs to be done for two purposes: 1) To check the polarity of the photodiode as they should be connected in reverse biased. 2) To check the maximum voltage range the sensor detects.
AT04	Placing the board at 3 different distances away from the IR LED and measuring the output voltage.
AT05	LEDs on the microcontroller turn on when a board is placed in front of it. This test will tell one if the output from the op amps are placed at the correct analog pins and the correct code is implemented that will toggle the necessary LEDs switch on when placed in front of it.

Table 2.3: Testing Procedures

2.4 Traceability Analysis

The show how the requirements, specifications and testing procedures all link, Table 2.4 is provided.

Table 2.4: Requirements Traceability Matrix

#	Requirements	Specifications	Acceptance Test
1	RID1	SID2,SID4	AT05,AT04
2	RID2	SID3	AT01
3	RID3	SID5	AT00
4	RID5	SID2	AT05, AT03
5	RID6	SID1	AT01, AT02

2.4.1 Traceability Analysis 1

The requirement from RID1 states that the micro-mouse needs to detect a wall at 3 different locations. This means that the micro-mouse will encounter the wall at 3 different locations and this will be the AT1.The micro-mouse will be tested to see if it can detect the wall at the right hand side of the micro-mouse, in-front of the micro-mouse and at the left hand side of the micro-mouse. When a wall is detected, the specifications of SID2 requires that the output be sent to the processor boards pins which will be the analog sensor inputs. The sensing must also have a large detection range that for the walls. In AT05, this clearly states on how a wall will be placed to check if the requirements are met.

2.4.2 Traceability Analysis 2

The requirement from RID2 states that one must design for power efficiency in order to not drain the battery quickly. This corresponds to the specification SID3, when the sensors are not in operation then sensors should be deactivated to save power.

2.4.3 Traceability Analysis 3

The requirement stated by RID3 states that one must design the board so that it fits on the pins from the motherboard.This corresponds to the specifications from SID5 that states that the PCB should not exceed the maximum dimensions of 70mm x 35mm. When the board arrives, a continuity check and board inspection shall be conducted to ensure it is able to fit onto the motherboard through the provided pin headers and this is stated in AT00.

2.4.4 Traceability Analysis 4

From RID6, the requirement stipulates that the sensor subsystem should operate on the voltage given by the power subsystem. The specifications of SID1 , requires that the voltage be 3.3V and therefore turn on the sensor circuits. In AT01 and AT02, the measured voltage across the IR LED will give one the indication that the circuit operates on 3.3V, and if it does then in AT02 the IR LED will switch on and emit infrared light.

Chapter 3

Subsystem Design

3.1 Design Decisions

3.1.1 Final Design

The following sensor design was chosen based on simplicity. It follows the idea of a proximity sensor which detects physical objects at a particular distance. IR proximity sensor typically has two main components, which is the Photodiode and IR LED. The IR proximity sensor works on the principle in which the IR LED emits infrared light and the Photodiode senses that infrared light.Photodiode resistance changes according to the amount of IR radiation falling on it, hence the voltage drop across it also changes. The IR LED and Photodiode were placed in an indirect incidence, meaning the components are placed in parallel with each other and and facing the same direction. Therefore when an object is detected, the infrared light get reflected and sensed by the photodiode.

Unique Design Decision 1

The combination of an IR Led and Photodiode was chosen as it was the best suited for a fast micromouse compared to a combination of an IR Led and phototransistor. A phototransistor is essentially a transistor that is sensitive to light. When light hits the phototransistor, it generates a current proportional to the light intensity, amplifying the signal internally. The combination of a phototransistor and an IR LED can be used for a micromouse but certain advatanges of an IR LED and Photodiode combination outweighed the combination that included the phototransistor.

	Photo-transistor and IR LED Combination	Photo-Diode and IR LED Combination
Advantages	• Higher Sensititvity • Built-in Amplification • The output signal from a phototransistor is stronger and smoother therefore signal can be processed efficiently.	• Quicker response time • Broader Spectral Response • Flexibility in Design
Disadvantages	• Slower Response Time • Narrower Spectral Response	• Lower Sensitivity

Table 3.1: Advantages and Disadvantages of a phototransitor circuit and photodiode circuit

Based on the information in the table, a phototransistor is not ideal for the micromouse as a micromouse needs a faster respose time in order to solve the maize quickly. The sensitivity of a photodiode can be mitigated and hence determined through resistor calcaulations and therefore a photodiode is well suited for this type of application over a phototransistor.

Unique Design Decision 2

Seeing that a photodiode and an IR LED combination will yield better results for the micromouse, one needed to decide whether the component connection should be in the form of a Reflective Object Sensor (Integrated Component) or connected the components individually. A reflective object sensor (integrated component) is a single component that consists of a IR LED and photodiode. The following table will differentiate between the two components connections.

	Reflective object sensor (Integrated Component)	Photo-Diode and IR LED individual connection
Pros	• Ease of Use - simplifies the design process since alignment of the photodiode and IR LED are pre-engineered. • Compact Size - Integrated component is smaller.	• Customised - one can change the angles, distances of the IR LED and photodiode to suit the requirements • Flexible Design - allows for a variety of configurations. • Flexibility in Design - the separate photodiode and IR LED can be individually analysed.
Cons	• Fixed Specifications - limited ability to modify the internal configuration. • integrated sensors are more expensive than individual components.	• Size - separate components can take up more space. • Alignment Challenges - precise alignment is crucial and can be challenging to maintain

Table 3.2: Advantages and Disadvantages of an integrated component and individual component

Unique Design Decision 3

The initial approach was to use a potentiometer connected to the non-inverting terminal of the op-amp. This potentiometer would be used to control the sensitivity of the photodiode and therefore can be varied as one wishes. The combination of the potentiometer and op amp would be seen as a voltage comparator. This would look into the principle when voltage at non-inverting input is higher than the voltage at inverting input, then the output of comparator is high. And if the voltage of inverting input is higher than non-inverting end , then output is lOW. The overall design would be sufficient and would yield the expected results but due to the limitations and the budget one has, using a potentiometer would not be ideal as it will place one over the given budget. Hence the designing of the negative feedback.‘Negative feedback is a situation in which a signal that is proportional to the output signal but has a phase that opposes the input signal is fed back to the input of an amplifier, or other circuit’. Albeit that one’s final decision on using an op amp yields satisfaction, there are still flaws in the final op amp decision compared to the idea of a comparator. The following table will show the differences between the two op-amp configurations and their connections to the negative feedback and and comparator respectively:

	Negative Feedback	Comparator
Pros	• Fixed gain value. This gives one the control of the system’s output. • The Voltage range is know, this means we can predict the output.	• The comparator saves more power as it will only operate when the non-inverting pins voltage is higher than the inverting pins voltage. • One is able to fully control the sensitivity of the photodiode, if they are not satisfied. • Faster in operations.
Cons	• Calculation of gain value and thus components values based on prediction of output voltage, thus component values can be wrong. • The overall gain has a possibility of leading the output voltage to be larger than expected thus burning components.	• Comparators tend to be sensitive to noise and therefore can lead to false triggering. • Comparators tend to have propagation delay.

Table 3.3: Comparison between the two op amp configurations

Now that one has explained the reason regarding choosing the negative feedback operation rather than voltage comparator operation. The two circuits still have a similar set-up when one looks at the two main componenets, the Photodiode and IR LED. Given the components on JLCPCB, for the IR LED , a component value with a maximum current of 100mA and a minimum current of 10mA , the following resistor values were calculated for the IR LED: Assuming the voltage drop across a red LED is 1.8V (Vres) = 3.3V - 1.8V = 1.5V Rmax = Vres / (IR LED minCurrent) Rmax = 150 ohms Rmin = Vres / (IR LED maxCurrent) Rmin = 15 ohms And therefore the resistor value chosen was 100 ohms.

A photodiode with these specifications was chosen: Reverse Voltage (VR) = 30V maximum Open

Circuit Voltage (VOC) = 0.35V typical when illuminated (Ee = 5mW/cm2) Light Current (IL) = 30-40A typical when illuminated (VR = 5V, Ee = 5mW/cm2) Maximum resistance (Rmax) = VRmax / (IL min) Rmax = 30V / 30A = 1M Rmin = (Vbat - VOC) / (IL max) Rmin = (3.3V - 0.35V) / 40A = 73.75k And therefore the resistor value chosen was 82k ohms.

The voltage gain for the negative feedback, 1 + (Rf/Ri) = 6 Therefore Rf = 10k.

This is full component selection from JLCPCB for the entire sensor design:

Component	Quantity	JLCPCB PART NUMBER
IR LED	6	C405273
Photodiode	3	C405264
LM358 Dual op amp	2	C7950
100 ohm resistor	6	C22808
82K ohm resistor	3	C23254
10K ohm resistor	3	C17414
2K ohm resistor	3	C17944

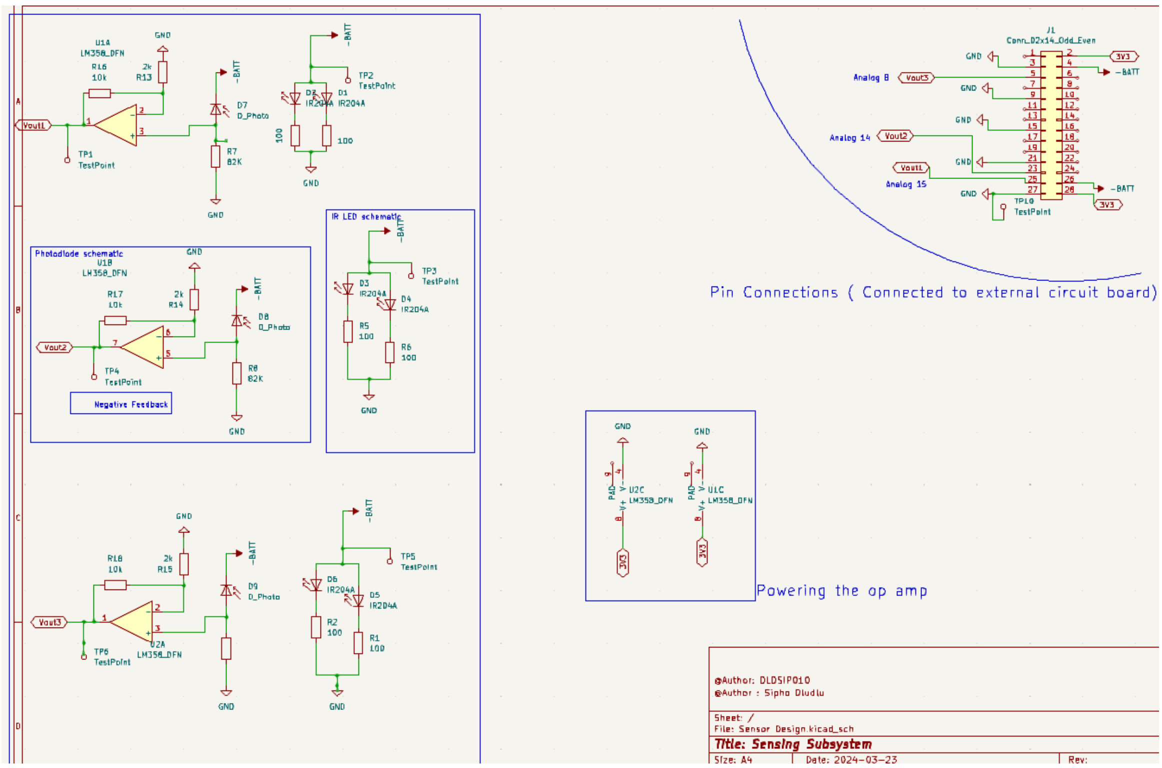
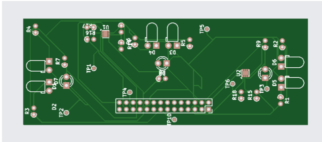
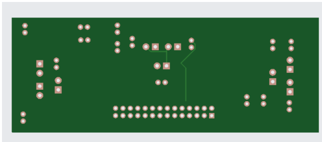


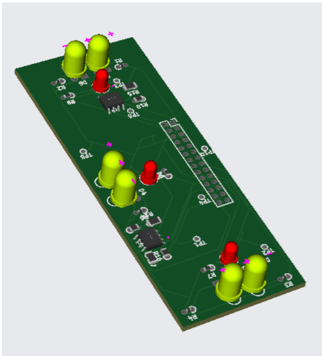
Figure 3.1: Final sensor schematic design



(a) Front PCB



(b) Back PCB



(c) 3D PCB

Figure 3.2: PCB Schematics

3.2 Failure Management

Test Point Id	Description
TP2, TP3, TP5	Test points were placed along the path from the battery (received from the power subsystem) to the circuit to ensure that the circuit is receiving the necessary voltage to power it on.
TP1, TP4, TP6	Test points were placed at each output of the op amp to check whether the op amp is operating and sending out the necessary output voltage to the processor board.

3.3 System Integration and Interfacing

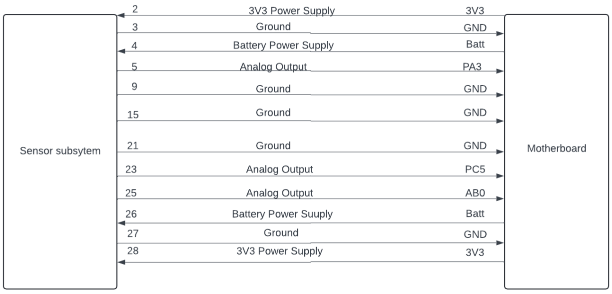


Figure 3.3: High level interfacing diagram

Table 3.4: Interfacing specifications

Interface	Description	Pin/Output
I001	Op amp output from right right sensor is connected to the analog GPIO pin in order to supply a signal to the microncontroller that will be processed by the ADC.	Output from Op amp to Pin 5 which represents GPIO PA5 of the microcontroller.
I002	Op amp output from left right sensor is connected to the analog GPIO pin in order to supply a signal to the microncontroller that will be processed by the ADC.	Output from Op amp to Pin 25 which represents GPIO AB0 of the microcontroller.
I003	Op amp output from front sensor is connected to the analog GPIO pin in order to supply a signal to the microncontroller that will be processed by the ADC.	Output from Op amp to Pin 23 which represents GPIO PC5 of the microcontroller.
I004	Battery voltage supplied from the power subsytstem is used to supply the voltage to the IR LED's and Photodiodes	Battery power supply from pin 4 and 26 of motherboard to the circuit .
I005	3v3 voltage from the motherboard will be used to power on the op amps in the sensing subsystem.	3v3 voltage supply from pin 2 and 28 of the motherboard to the op amps.

Chapter 4

Acceptance Testing

4.1 Tests

These tests must be repeated for every sensor circuit(right, left and front) but these tests are conducted one at a time, to ensure efficiency.

Test ID	Description	Testing Procedure	Pass/Fail Criteria
AT00	Using the multimeter to test for continuity across the components. This test will give one the indication if there is a short circuit or not within the components.	• Switch on the multimeter and set it to check for continuity. Place the probes at the points that are directly connected to each other and listen if the multimeter emits sound. Then place the probes at the points that are not directly conncetd to each other , for example the cathode of a current limiting resistor and the anode of an IR LED and observe the sound	If the directly connected paths emits sound then the paths are connected and the test passes but if the directly connected paths don't emit sounds then the test failed.
AT01	Using the supply voltage to power on the IR LED. This test will tell one if the supply voltage is sufficient enough to power the IR LEDs in the circuit and therefore enabling the IR LED to emmit light.	• Plug the circuit into a breadboard and connect a 3.3V supply from a power supply or microcontroller to the breadboard. Set the multimeter to measure the voltage by placing the anode probe on the anode of the IR LED and the cathode probe to the ground of the breadboard. • Switch the multimeter to current measurement mode and place it in series with the circuit to measure the forward current.	The fail criteria for this test is if the measured voltage drop and current across the IR LED is approximately the same as the datasheet's specified voltage and current (1.2V with a current of 100mA).

AT02	Infrared light cannot be seen with the naked eye. Testing whether the IR LED emits infrared light when connected to the power supply. This test will confirm if the LED is a normal LED that emits visible light or an LED that emits nfrared light.	• Connect the PCB to a breadboard and connect the 3.3V power supply to the breadboard.Find a phone that has a camera that does not filter out infrared light, preferable any android phone and not an ios phone. Point your camera to the LED and observe if there is light coming out of LED through the camera.	As one cannot see infrared light through the naked eye, the camera should show a purple-ish colour coming from the IR LED. If there is light, then this test will be classified as a pass.
AT03	Testing the output directly from the photodiode. The output from the photodiode should vary when an object comes closer to the IR LED.This test needs to be done for two purposes: 1) To check the polarity of the photodiode as they should be connected in reverse biased. 2) To check the maximum voltage range the sensor detects.	• Switch on the multimeter and set it to measure voltage. Connect the PCB board to a 3.3V power supply through a breadboard. Place the anode probe at the cathode of the photodiode and place the cathode probe to ground. Place your hand on the IR LED and slowly move your hand away from it.	The test passes if there is a voltage reading on the multimeter. This confirms that the photodiode is indeed connected in reverse biased as there is a voltage across it. This test passes when one moves their hand away from the IR LED and there is a change in the voltage being measured on the multimeter.
AT04	Placing the board at 3 different distances away from the IR LED and measuring the output voltage. This is done to see the detection range of the IR LED and will help one when configuring the ADC channels when coding the microcontroller.	Switch on the multimeter and set it to measure voltage. Connect the PCB board to a 3.3V power supply through a breadboard. Place the anode probe at the cathode of the photodiode and place the cathode probe to ground. Place the board at the furthest range (5cm) and observe the voltage on the multimeter. Move the board closer (2cm) away and observe the voltage. And finally move the board to within 0.5cm of the IR LED and observe the voltage on the multimeter.	There is no conclusive pass or fail criteria for this test as the sensor is able to sense. This test is done to be able to determine the ADC range when coding the microcontroller. Ideally one want to have the sensor sensing at the highest distance but the 2cm sensor works as it is still withing the range of the required range.

AT05	LEDs on the microcontroller turn on when a board is placed infront of it. This test will tell one if the output from the op amps are placed at the correct analog pins and the correct code is implemented that will toggle the necessary leds switch on when a placed infront of it.	Generate the code that will switch on the leds. Place the board 2cm away from the IR LED and adjust the ADC channels to switch on when there's a board infront of it.	When the wall is placed at the right of the micromouse, the LED connected to the circuit on the right should be the only one to turn on, if the other LED's turn on then the test is a fail.

Table 4.1: Tests

4.2 Critical Analysis of Testing

Test ID	Description	Result
AT00	Checking continuity between components to ensure there are no short circuits.	Pass.
AT01	Supply voltage sufficient enough to power on the IR LEDs.	Pass
AT02	IR Leds are emiting infrared light.	Pass.
AT03	Testing the polarity of the sensor and the whether it is able to sense the infrared light emitted.	Pass .
AT04	Testing that voltage varies as the wall is placed at 3 different distances	Pass .
AT05	Microcontroller is able to read the neccesaary output when a wall is placed at that particular sensor and thus switch on the LED for that sensor	Pass,

Table 4.2: Critical Analysis Testing

4.2.1 AT00

The PCB board had no short circuit as every trace had been connected successfully to the necessary component without. This is evident in the figure below as there is no scratching and scrapping on the PCB to remove short circuiting between components by removing certain traces.

4.2.2 AT01

Using the microcontrollers 3v3 port , a 3.3V voltage was supplied to the PCB . The measured current was a constant current of 98mA which is relatively close to the expected current of 100mA. The voltage drop across the LEDS was 1.2V.

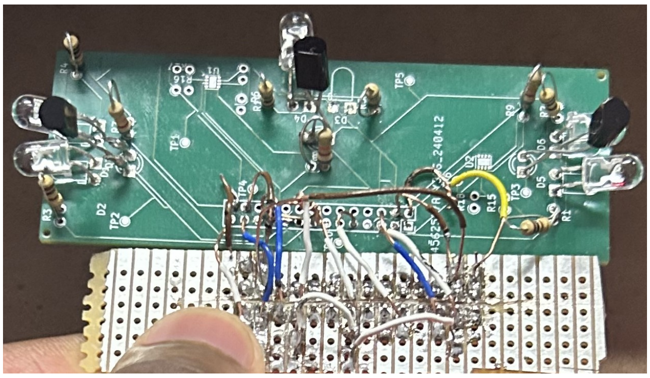


Figure 4.1: PCB

Figure 4.2: Final Schematic

4.2.3 AT03

The polarity of the senors were placed incorrectly. This led to the sensors not sensing at the first try. One had to desolder the sensors and therefore resolder them in the correct orientation in order for them to sense. Upon testing, one found that the sensing range of the photodiode was not great and therefore desoldered them again and replaced them with SFH205 photodiodes as they have similar characteristics. If one looks at the in AT00, will notice the soldering and replacing of the photodiodes. After testing one, these produced better results and one can differentiate when the hand was placed very close to the sensor and when the hand moved really far.

4.2.4 AT04

The hand placement in AT04 produced different voltages compared to using a brown board. The voltages varied as they were placed at the 3 different positions. The brown board absorbs light so yielded less output voltage from the photodiode as not a large amount of voltage was read but this was not the main testing purpose. When the wall was placed 5cm away from the circuit, there was a very low voltage being read, but when the board was placed 2cm away from the circuit, there was voltage increase but it was not that high. This meant that one's sensitivity was not that high and therefore did not yield the expected results. When calculating the resistor connected to the photodiode, the resistance chosen was relatively smaller and one should've chosen a higher resistance. This was not taken into consideration when designing the PCB hence there was no failure management for it.

4.2.5 AT05

When the code was generated and flashed into the microcontroller to output the nececssary LEDs when a certain of the sensor circuit is facing a board, the necessary LEDs turned on but not instantly.

As stated in the testing of AT04, the photodiodes did not have high sensitivity therefore the ADC

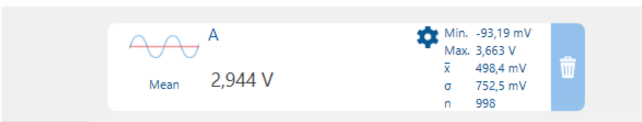


Figure 4.3: Hand placed close to the IR LED

Figure 4.4: Hand placed far away from the IR LED

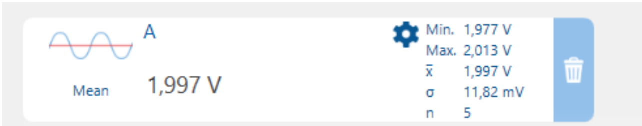


Figure 4.5: 0.5cm away from circuit

channels have to be configured and changed as the testing went on to find the perfect range.

In the above figure, one can observe on how close the circuit has to be to the board in order for the microcontroller's LED to switch on. Albeit the sensitivity was not relatively high, the outputs was connected to the correct analog pins and therefore configured to produce the necessary results when they encountered a board. Below are the results of the tests.

Figure 4.6: All 3 sensor circuits facing a wall

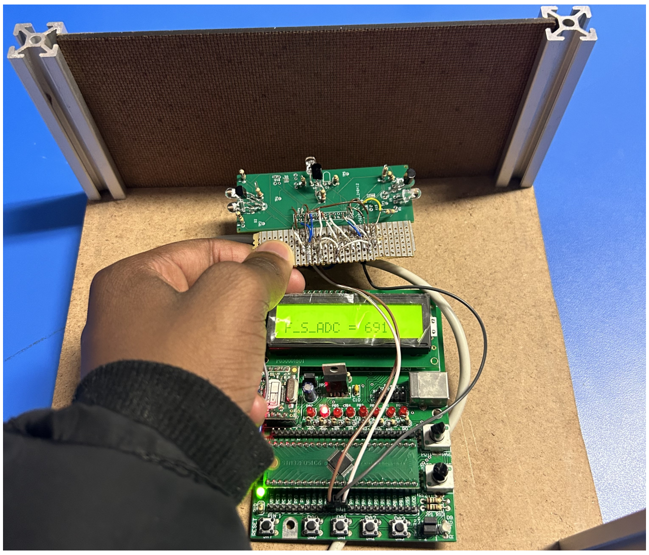


Figure 4.7: Front sensor facing a wall

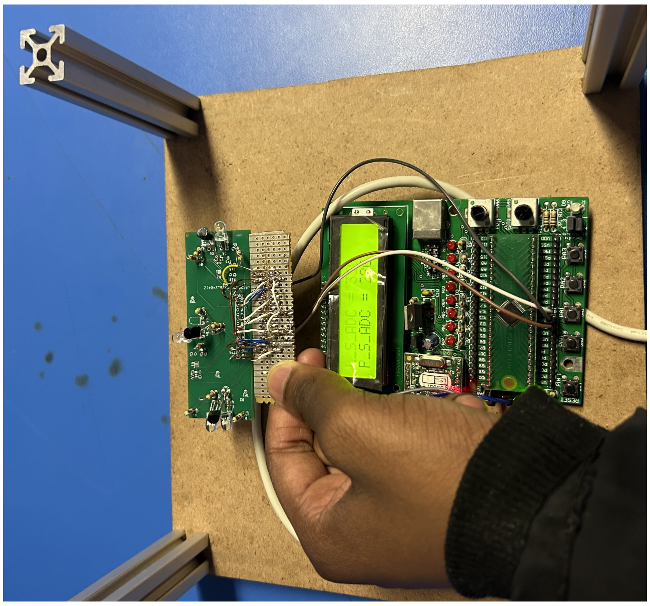


Figure 4.8: No walls detected

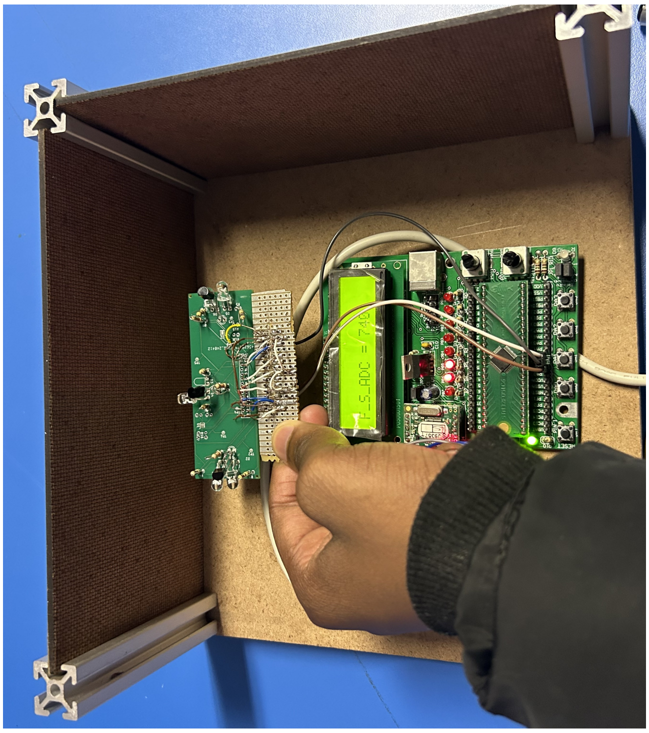


Figure 4.9: No left wall

Chapter 5

Conclusion

The sensor subsystem produced the expected results. The sensor was able to detect the wall the wall at 3 different locations, the left side of the micromouse, the right side of the micromouse and the front of the micromouse. Although the sensors , did not have a high sensitivity they produced what was stipulated for the problem , to be the eyes of the micromouse. The sensor circuit and the coding of the microcontroller , was designed to ensure that the sensors detected the walls quickly when they are in the range designed for and therefore it serves the general purpose of the micromouse to solve the maze in the fastest time possible. Albeit the senors work and at a quickly manner , the design lacked switching means to save power. This would result in the micromouse, having it's battery drained quickly. The design lacked failure managements and when problems were encountered, like the resistances for the photodiodes one could not mitigate such. Overall as the design had its flaws but it solved the general description of being the eyes of the subsystem.

5.1 Recommendations

For suggestions, one would suggest, signal conditioning which means to incorporate filters to remove noise and improve signal quality. Use low-pass filters to smooth out the sensor signal. Environmental Calibration which means calibrate sensors for different environmental conditions, such as varying light levels and surface types.